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Driver Performance Model: 1. Conceptual Framework

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Abstract

A comprehensive model that combines the necessary aspects of vehicle characteristics, manual control theory, and human sensory and cognitive capabilities (and limitations) is needed to efficiently and effectively guide experiments and to predict or assess overall driver performance. Such a model would enable an Army program manager to rank competing workload configurations and scenarios in proposed vehicles and to select the one(s) most promising, thereby saving resources otherwise spent on the current process, that is, multiple hardware iterations of "design-test-fix."

At the present time, no such comprehensive model exists. This report discusses a conceptual framework designed to encompass the relationships, conditions, and constraints related to direct, indirect, and remote modes of driving and thus provides a guide or "road map" for the construction and creation of a comprehensive driver performance model.

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1. Introduction

Three modes of driving a vehicle are defined: direct, indirect, and remote. The routine "through-the-windshield" driving of a high mobility multipurpose wheeled vehicle is an example of a vehicle driven directly. The on-board driver, who uses image intensifiers or forward looking infrared optical systems to navigate a vehicle at night, provides an example of a vehicle driven indirectly. The situation in which the driver is physically separated from the vehicle being driven defines remote driving. The teleoperation of an unmanned ground vehicle provides an example of remote driving.

The use of the terms "direct," "indirect," and "remote" driving usually implies a visual orientation[1] because driving is primarily but not exclusively a visual task[2]. In this report, because better terminology is not yet available, each of these terms is assigned a broader meaning, as outlined in Table 1. When this broader meaning is intended, these words are underlined (e.g., <u>indirect</u>). Table 1 shows the sources of stimuli that activate the human senses, which are considered in this report: visual, auditory, vibrational, and vestibular. These stimuli are deemed the most important in any of the three driving modes. Two sources of stimulus for the auditory sense are explicitly recognized: (a) internal environment, which includes noises from the engine and the vehicle[3], and (b) external environment, which includes the sounds from the environment outside the vehicle[4]. The vestibular organs sense the body's position with respect to the vertical (Sanders & McCormick, 1993). Italics are used in Table 1 to indicate those areas in which relatively few studies have been done. For example, in Table 1, the <u>direct</u> and <u>indirect</u> modes of driving have the same sources of the stimuli for the driver's internal auditory, vibrational, and vestibular senses. These modes differ in their visual and external auditory stimuli. The italics for the <u>indirect</u> external auditory stimulus show that this area has not been well studied.

In both the <u>indirect</u> and <u>remote</u> modes of operation, critical visual, audio, vibrational, or vestibular cues are diminished or altogether missing. Experiments

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[1]Humans are visually oriented. As Sanders and McCormick (1993) point out, "...misperceptions of the true upright direction may occur when there is a conflict between the sensations of gravity (detected by the vestibular organs) and visual perceptions; in such a case, one's visual perceptions usually dominate, even when they are erroneous."

[2]Consider the extremes: deaf people can drive and blind people cannot.

[3]These "routine" noises have sometimes been called "incidental sounds" (private communication, Haas, 2001).

[4]When external auditory sensors (e.g., microphones) are used, some form of active or passive noise cancellation would probably be used to reduce the external engine noise of most large vehicles.

have been conducted (e.g., see McLane & Wierwille, 1975) and hypotheses are being developed to understand how these cues affect driver performance and how best to compensate for their diminution or loss. A comprehensive model that combines the necessary aspects of vehicle characteristics, manual control theory, and human sensory and cognitive capabilities (and limitations) is needed to efficiently and effectively guide these experiments. Such a model would also predict and assess overall driver performance. At the present time, no such comprehensive driver performance model exists.

Table 1. Sources of Stimulus for Three Modes of Driving

Human senses		Direct stimulus from	Indirect stimulus from	Remote stimulus from
visual		"through windshield"	sensor-display	sensor-transmission-display
auditory:	Internal*	environment	environment	*sensor-transmission-display*
	external	environment	*sensor-display*	*sensor-transmission-display*
vibrational		vehicle**	vehicle**	*sensor-transmission-display*
vestibular		vehicle**	*vehicle***	*sensor-transmission-display*

*engine and vehicle noises
**transmission of vehicle's response to the terrain.
Italics indicate areas in which relatively few studies have been done.

To construct such a model, a conceptual framework is first developed. A conceptual model helps frame the problem and defines what needs to be modeled (Lee, 1998). Ideally, all the relationships, conditions, and constraints among the elements (i.e., parameters and variables) that describe driving are identified. The immediate utility of this framework derives from its assembly, during which those areas that are deficient in or devoid of information can be highlighted for study[5]. The author envisions augmenting the conceptual framework in a continuous or iterative fashion to produce a functional, predictive driving model. Appropriate mathematical formalisms relating dependent and independent driving variables are used to convert a conceptual model into a computational model (Lee, 1998). We can accomplish this evolution by critically examining the information available from the literature and from current research, by guiding ongoing avenues of research, and by suggesting new ones.

Once such a modeling tool has been developed and verified, Army program managers will be able to predict and compare soldier-vehicle performance for all

[5]The italicized entries in Table 1 provide examples of this highlighting, albeit at a highly abstract level.

future conceptual and developing vehicle systems. The completed model will enable the program manager to rank competing workload configurations and scenarios for the vehicle and to select the one(s) most promising, thereby saving resources that would have been spent on the current process, that is, multiple hardware iterations of "design-test-fix" (private communication, Harrah, 1999). This report discusses a conceptual framework designed to encompass the relationships, conditions, and constraints related to the three driving modes: direct, indirect, and remote.

2. Conceptual Framework for Driving

The overall technical challenge is to create a model that identifies the relationships among the important variables affecting driver performance for direct, indirect, and remote driving modes. The goal of the current work is to develop a crew station model applicable to all three modes of driving. Relationships among the three driving modes are portrayed in Figure 1, which is composed of **critical elements** that are the subject of the remainder of this section.

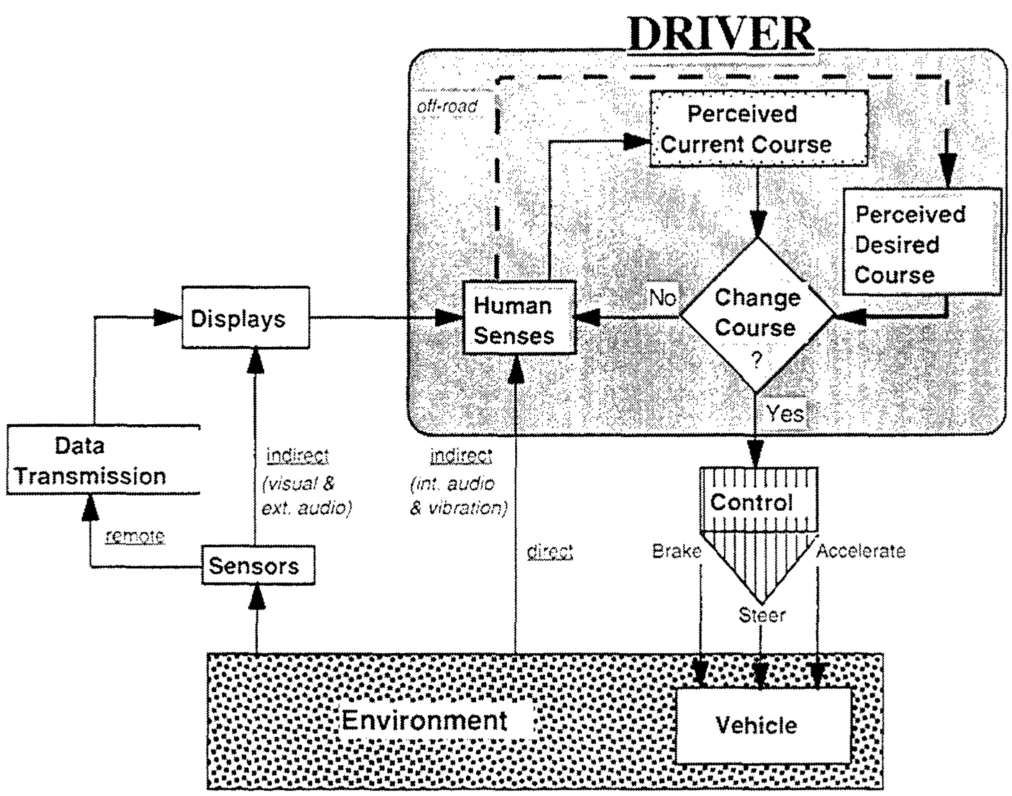

Figure 1. Schematic Diagram for Direct, Indirect, and Remote Driving.

For any driving mode, the three major functions of the driver are

1. To determine the current course (or present course location),

2. To decide whether this course is tracking (or the present course location corresponds to) the desired course, and if not,

3. To make appropriate and necessary corrections in the vehicle's course.

When driving takes place on a roadway, the desired course is usually well defined. When driving off road, the driver has the additional task of selecting the "desired" course[6]. The decision to alter course is based on the driver's judgment of how well his or her perception of the actual course of the vehicle matches his or her perception of the desired course.

The **perceived current course** is determined by what is presented to the driver's senses and how this information is interpreted[7]. The correspondence between the **perceived desired course** and the actual course is a matter of driver interpretation and is subject to errors of judgment[8]. The cognitive difficulty in determining the actual course is, among other factors[9], a function of whether the mode of driving is <u>direct</u>, <u>indirect</u>, or <u>remote</u>.

A **perceived desired course** may be defined as a path that enables one to move a vehicle to a specified location with a minimum of difficulty and as quickly as practical, that is, within the constraints of the mission, the person, the vehicle, and the environment (private communication, Harrah, 2001). The **perceived desired course** is presumed to be known in space and time or is iteratively determined. An example of the former situation is directing, for example, a Bradley fighting vehicle to travel over a system of roads from an assembly area to an engagement area by a certain time. An example of the latter situation is the maneuvering of a vehicle in an off-road scenario. The dashed line labeled *"off-road"* in Figure 1 acknowledges the fact that the desired course may have to be iteratively determined while the vehicle is being driven. That is, the driver must select the path to traverse since there is no road. In the *off-road* situation, the driver is more cognitively loaded, and the driver's understanding of a **perceived desired course** is subject to greater errors of judgment.

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[6]Even when driving on a roadway with obstacles (e.g., with pot holes or bomb craters), the driver must select an appropriate "desired" course.

[7]The ability to interpret is a function of many variables, such as training and fatigue.

[8]Global positioning system (GPS) information could accurately provide the current location of the vehicle and its final position. In the opinion of the author, GPS appears to benefit on-road travel more than off-road travel, where other factors such as the determination of the vehicle's path between trees, around boulders, and across ditches seems to be the more immediate and critical challenge (see, for example, Collins, Piccione, and Best, 1998).

[9]For example, one would normally expect off-road driving to increase the driver's cognitive workload.

By comparing the **perceived current course** with the **perceived desired course**, the driver decides whether to **change course**. If the driver decides that the vehicle is on course, the answer is "no." The driver does not alter the **control** settings of the vehicle and continues to scan the displays (or performs other functions not shown in Figure 1). If the answer is "yes," the driver will activate one or more controls to alter the course of the vehicle. Among the methods of vehicle **control**, a wheel to **steer** and pedals to **brake** and to **accelerate** are common methods to change the velocity of the vehicle. Therefore, in addition to the cognitive aspects of decision making, there are anthropomorphic or psychomotor issues of the physical location of the controls with respect to the driver and the ease with which they can be used[10].

The velocity of a land vehicle can be considered a two-dimensional vector[11], $\mathbf{v}$, which includes the concepts of both speed and direction. The speed is a scalar and is given by $|\mathbf{v}| = v$. The direction is supplied by the unit vector, $\mathbf{n}$. Since steering may be considered a change in direction, for example, $\Delta\mathbf{v}$, and since the derivative of velocity with resepct to time, $\pm[d\mathbf{v}/dt] = \pm\mathbf{a}$, corresponds to accelerating ($+\mathbf{a}$) or braking ($-\mathbf{a}$), then formally only changes in the velocity vector need to be considered to totally describe the control of the vehicle's motion[12]. However, in the literature, depictions of vehicle control typically have been separated[13] and so they are considered as distinguishable methods of control in the scheme presented in Figure 1.

The **vehicle**, whether military or civilian, has its own limitations and capabilities. Each type of vehicle has its own suspension and handling characteristics. For the <u>direct</u> and <u>indirect</u> modes, the driver is physically present in the vehicle and is subject to its motions and vibrations (see Table 1). For the <u>remote</u> driving mode, the driver is not in the vehicle[14].

The vehicle itself exists within an **environment** (see Figure 1), which is affected by time of day, weather, and obscurants (e.g., smoke or dust). The surface over which the vehicle is being driven can be considered part of the environment. The model should account for the vehicle's response, which is a function of its characteristics and the road or terrain over which the vehicle is being driven[15]. In addition, if the vehicle is part of a convoy, the **environment** could include

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[10]A driver would be expected to experience a different "feel" for the same vehicle, depending on whether its linkages were hydraulic or drive by wire (private communication, Harrah, 2001).

[11] In two-dimensional Cartesian coordinates, $\mathbf{v} = v_x\mathbf{n}_x + v_y\mathbf{n}_y$, and $\mathbf{v}\bullet\mathbf{v} = v^2 = v_x^2 + v_y^2$.

[12] Mathematically, the change in vehicle velocity is given by $\Delta\mathbf{v} = (\mathbf{v} - \mathbf{v}_o) = \mathbf{a}\, t$. The integral of this expression provides the change in the vehicle's location: $\Delta\mathbf{x} = (\mathbf{x} - \mathbf{x}_o) = \mathbf{v}_o t + 1/2\, \mathbf{a}\, t^2$.

[13]See for example, McRuer, Allen, Weir, and Klein (1977) or Sharp, Casanova, and Symonds (2000), who have used steering, braking, and velocity as explicit methods of vehicle control.

[14]At the present time, whenever the driver of a remote vehicle is placed in a second vehicle, that driver is subject to the effects of motion, orientation, and vibration of the second vehicle.

[15]The model could also incorporate limiting parameters, such as the maximum angle to drive safely on an incline or the maximum speed to negotiate a turn safely.

whether it is the lead vehicle or a following vehicle. When driving on a dirt road, the drivers of following vehicles may be subject to the dust from the lead vehicle. When driving off road, the driver of the lead vehicle has the responsibility to select a path that others may follow. Depending on weather and terrain, the drivers of the following vehicles may also be subject to dust.

In the direct mode of driving, none of the stimuli are supplied to the driver's senses through a display; all are supplied to the driver's **senses** directly from the environment[16].

In the **remote** mode of driving, all the stimuli to the driver's senses are supplied by means of displays[17] (see Table 1). The suite of visual, auditory, vibrational, and vestibular **sensors** employed is critically important, for it is through these data, transmitted to their corresponding **displays,** that the remote driver perceives the vehicle's local environment[18]. The remote driving mode requires **data transmission** from **sensors** to distant **displays** (see Table 1 and Figure 1). Sensor data[19] could be transmitted through physical links, such as an optical fiber, or through wireless links. Wireless transmission may be further classified by frequency and bandwidth or by whether the data are encoded.

Indirect driving can be viewed as a hybrid mode that has some characteristics of the direct and the remote driving modes. In the **indirect** mode, the visual and external auditory[20] stimuli are presented to the driver by means of **displays,** while the internal auditory, vibrational, and vestibular stimuli are obtained directly from the environment by the driver (see Table 1). In the **indirect** mode of driving, the suite of **sensors** employed is again critically important, for it is through these sensors that the on-board driver perceives the vehicle's local environment.

The **human senses** determine what the driver sees, hears, and feels. The **human senses** of the driver are used to perceive the vehicle's local environment directly or indirectly through the use of sensors and displays. The driver evaluates this information and determines a **perceived current course** of the vehicle, compares it with the **perceived desired course**, and decides whether to **change** the current

[16]This includes the vehicle's vibrations and the vestibular response of the driver, which are not explicitly shown in Figure 1.

[17]Here, "display" includes not only visual but may also include auditory, vibratory, and vestibular input.

[18]Glumm, Kilduff, Masley, and Grynovicki (1997) found that for any remote driving system, relatively small changes in the location and angle of the camera on board the remote vehicle affect the driving scene, which, in turn, can significantly impact the remote driver's performance.

[19]In the remote driving mode, control commands must also be transmitted.

[20]The external audio has not usually been presented to the driver.

course[21]. The driver continuously iterates the cycles given in Figure 1 until a final location or end time for the driving task or mission has been reached[22].

3. Discussion

With the same or similar elements depicted in Figure 1, a schematic of autonomous mode of driving has been sketched in Figure 2. Here, the **DRIVER** of Figure 1 has been replaced by **Computer** in Figure 2, and all but the **vehicle**, **environment**, and **sensors** of Figure 1 have been replaced by a series of **computational algorithms**.

The author perceives a long lead time in the fielding of operationally autonomous units.

> Despite the increasing trend toward automation and robotics in many environments, the human operator will probably continue for some time to be integrally involved in the control and regulation of dynamic physical systems (Wickens, 1986).

Horgan (1996) concluded

> Artificial vision remains one of the most profoundly difficult problems in artificial intelligence.

And more recently,

> How are details perceived in images? Although the experimental facts are quite well known, the conditions under which the higher cognitive centers can "fill in" missing information have not been properly worked out. Moreover, filling in of missing information can presumably work well only when the observer is preconditioned at least to the image class. Even when this is the case, there is a danger that what is "filled in" is wrong (Wells, 1997).

If the details of human perception of images are not understood, it is unlikely that a satisfactory visual sensor package will be able to be constructed so that a vehicle might autonomously navigate its environment. Thus, autonomous

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[21]"Good situation awareness should increase the probability of good decisions and good performance, but it does not guarantee it" (Endsley, 2000). Situational awareness might be succinctly defined as knowing what is going on in the local environment (Endsley, 2000). Thus, the effectiveness of the decision whether to change course is affected by the driver's situational awareness, which in turn, is related to the fidelity of the suite of sensors in the indirect and remote modes of driving and to the physical and mental state of the driver in all modes of driving.

[22]The notions of final location and end time include mission failure (e.g., getting the vehicle stuck in the mud).

vehicles[23], which only occasionally may require monitoring by a human, are still some time in the future. It appears that vehicles will be operated by a human driver in the direct, indirect, or remote mode for some time to come. Indeed, the completed model of driver performance might be used to gain insight about how one might structure an autonomous vehicle.

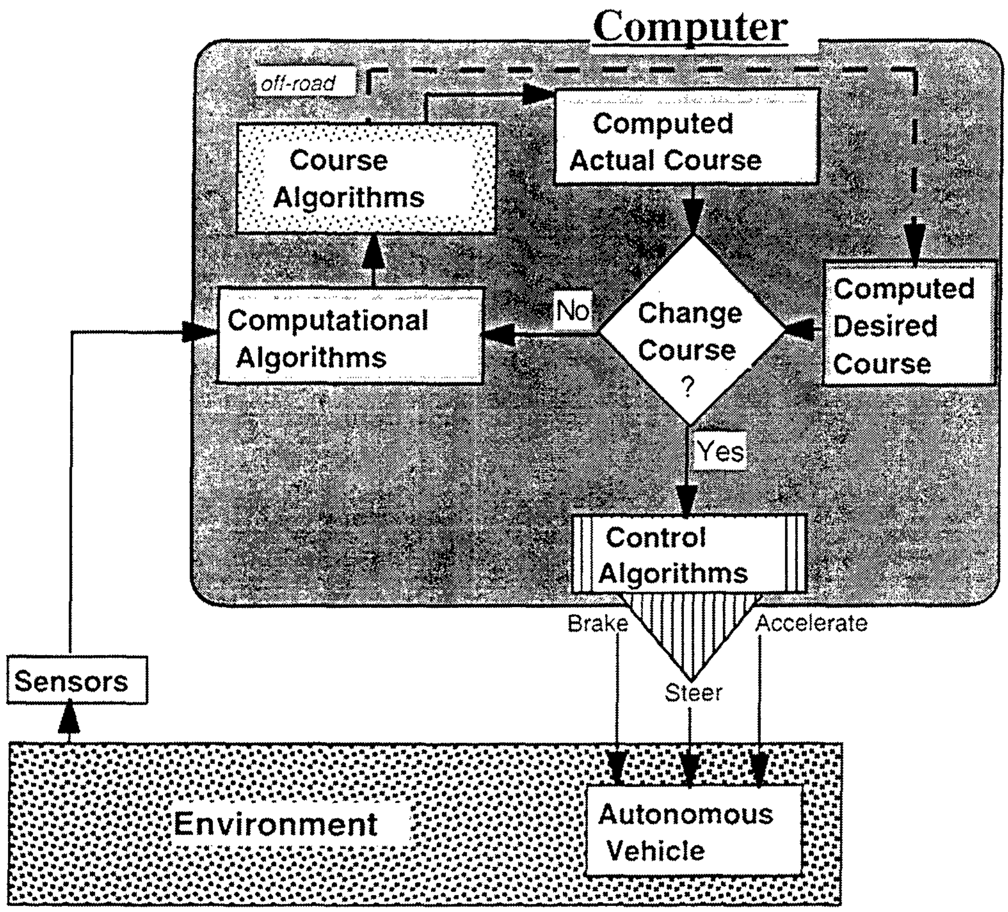


Figure 2. Schematic Diagram for Autonomous (robotic) Driving.

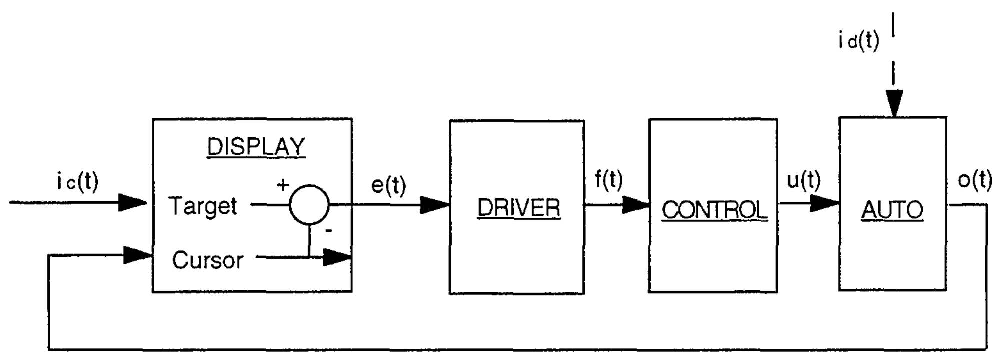
The conceptual framework for driving, which is given in Figure 1, is not the only framework that has been used. A description of driving has been supplied by McRuer, Allen, Weir, and Klein (1977):

> Driving consists of a hierarchy of navigation, guidance, and control phases conducted simultaneously with visual search, recognition, and monitoring operations. Fundamentally, navigation is the overall selection of a route; to accomplish navigation involves a series of guidance and control operations. Guidance is concerned with more specific questions of path details and judgments, based on the given situation. Typically, guidance is made up of the selection, decision,

[23]The "semi-autonomous" vehicle is equivalent to the remote mode of driving.

and the definition aspects of one task... Control is the process of effecting the guidance desired by actuating the steering wheel, accelerator, and brakes in such a way that the selected path is followed at the desired velocity, and with acceptable accuracy.

Figure 3 shows a conceptual framework of the basic elements of driving an automobile, according to Wickens and Hollands (2000). They explain that while driving over a roadway, the driver may perceive a discrepancy or error between the desired trajectory of the vehicle and its actual trajectory. They state that successful driving requires *three important components* (Wickens & Hollands, 2000). Two of these components, *clear goals* and *knowledge of the current state of the vehicle,* correspond to the elements of **perceived desired course** and **perceived current course** of Figure 1. The third component of Wickens and Hollands (2000) is *an accurate mental model of the vehicle's response,* which is implied in the element whether to **change course** in Figure 1.



$i_c(t)$ = input "command" = desired position
target = input signal on display = $i_c(t)$
e(t) = error = [o(t) - $i_c(t)$]
f(t) = force applied by driver
u(t) = mechanical response to applied force
$i_d(t)$ = input disturbance
o(t) = output = current position
cursor = output signal on display = o(t)

Figure 3. Elements of Driving (Wickens & Hollands, 2000).

Wickens and Hollands (2000) continue with an example to illustrate the conceptual framework of Figure 3. An automobile may have deviated from the center of the lane[24] and the driver wishes to reduce this error, e(t), which is a function of time. To do so, the driver applies a force, f(t), to the steering wheel (the control in Figure 3). This torque produces a rotation, u(t), of the steering wheel itself, and because of the mechanical and hydraulic linkages to the tires, causes the automobile's position to move laterally on the highway. The change in the automobile's position is the output, o(t). (Table 2 provides a cross listing of the different terminology used in this report and in Wickens & Hollands, 2000.) The symbol representing the output position on a (visual) display is called the cursor. If the operator is successful in the correction, it will reduce the

[24]On stretches of two- and four-lane highways, drivers tend to stay almost exactly in the center of their lanes, and the dispersions of positions about the center are small and nearly normal in shape (Soliday, 1975).

discrepancy between the automobile's position on the highway, o(t), and the desired (or "command") position at the center of the lane, $i_c(t)$. The symbol representing the desired input on a display is called the target. The difference between the output signal (i.e., the cursor) and the input signal (i.e., the target) is the error, e(t)—the starting point of this illustration. The skilled driver will respond in such a way as to keep $o(t) \approx i_c(t)$, so that $e(t) < \varepsilon$, the upper limit of acceptable error[25].

Table 2. Corresponding Terminology

Wickens and Hollands (2000)				This report
Manual control theory		Seen on display		
command input	=	target	-->	perceived desired course
output	=	cursor	-->	perceived current course

In Figure 3, the input $i_d(t)$ is defined as a disturbance applied directly to the automobile. One example is a gust of wind that pushes the automobile off center lane. Another example is the accidental movement of the steering wheel by the driver (Wickens & Hollands, 2000). These types of "noise" input could have been made explicit in Figure 1 for the elements **control**, **vehicle**, **sensors**, **data transmission**, and **displays**. However, to keep the schematic relatively simple, they have not been included[26] .

In the terminology of pursuit tracking literature, the driver sees both the input (the target) and the output (the cursor) independently. In our terminology, the input is the **perceived desired course** and the output is the **perceived current course** (see Table 2). Driving is pursuit tracking[27] in which the operator sees both the input (or target) and the output (or cursor) independently and tries to match them (Sheridan & Ferrell, 1972). When they are matched, the vehicle is "on target." The tracking loop depicted in Figure 3 is a conceptual model of driving whose computational analog is determined by manual control theory. It does not contain the level of detail thought necessary to specify and study the relationships among critical driving elements (see Figure 1).

[25]Ideally, $o(t) = i_c(t)$ and $e(t) = 0$.

[26]The "noise" input was not depicted for the **control** and **sensors** elements of Figure 2, either.

[27]In compensatory tracking, the operator sees only the error between the input and the output, but the goal is still the same: to null the error between the input and the output (Sheridan & Ferrell, 1972).

Figure 1 provides a conceptual framework to "see" the relationship between the elements and allows the elements to evolve from abstract into more concrete, practical operational (sub-) models. Consider the interaction between the elements of **vehicle**, (visual) **displays,** and the **human senses** in the indirect or remote modes of driving. Vestibular receptors respond only to angular and linear accelerations (Reason, 1978). Vestibular-visual interactions are important in provoking motion sickness (Bles & Wertheim, 2000; Yardly, 1992). Visual information that does not agree with information from the vestibular (and other) sensory receptors promotes motion sickness in most cases (Money, 1970).

Many direct driving studies have been performed on well-defined roadways (real or simulated). In this context, the goal is to keep the vehicle traveling along the center of the driving lane. Important cues for navigation are supplied by the boundaries of the roadway[28]. In addition, direct driving allows one to preview the roadway[29], which is critical[30]. In either the indirect or remote driving modes and depending on the level of sophistication and the inherent limitations of sensors and displays, previewing may or may not be present to the same extent. In addition, indirect or remote modes of driving in a military context presuppose off-road driving over open terrain, and so the standard cues available in direct driving may be impoverished or altogether missing[31, 32].

In Figure 1, any of the elements (**control, vehicle, environment, sensors, or displays**) may be either real or simulated. When any or all these real elements are replaced by their virtual counterparts, the schematic in Figure 1 can describe the many permutations of virtual or simulated driving.

4. Implementation Strategy

This section describes a strategy to convert the conceptual framework (given in Figure 1) into a computational, predictive model. To accomplish this, suitable quantitative representations for each of the elements need to be found or created.

[28]On curves, drivers tend to scan the inside edge of the roadway (Shinar, Rockwell, & Malecki, 1980). Gordon (1966) found that all drivers on a two-lane road with low traffic density guided their vehicles by referring to the road edges and the center line.

[29]On curved roads, drivers try to maintain a preview distance corresponding to (3 ±0.5) seconds (Shinar, McDowell, & Rockwell, 1977).

[30]Gordon (1966) reported that drivers traveled as fast as 25 km/hr on a curved two-lane road with a monocular field of view as small as four degrees. This ability was attributed to the presence of road edges and the center line.

[31]For example, with some configurations of sensors and displays, remote drivers tend to overestimate distances and clearances, that is, they get too close to obstacles before correcting their course, and they try to drive through gaps that are too narrow for passage (Miller, 1988).

[32]For either on-road or off-road driving, it is an assumption that performance in the indirect or remote modes must approach or exceed performance in the direct mode. The goal in a military context is to drive well enough to achieve the mission (private communication, Harrah, 2001).

These representations may take the form of computational (sub-) models, descriptive mathematical relationships among pertinent variables[33], empirically determined "laws," experimentally determined limits, or physical and psychological theories. Next, the representations of each of the critical elements need to be integrated, so that the output of one element becomes the input of the next. Finally, the underlying assumptions among the quantitative representations need to be mutually compatible.

A flow chart that describes this strategy is shown in Figure 4. Two distinguishable phases are noted. Phase 1, identified by a dark background, outlines the strategy for accepting and validating individual elements or sub-models. Phase 2, whose background is white, outlines the strategy for integrating the sub-models of Phase 1 into a comprehensive driver model.

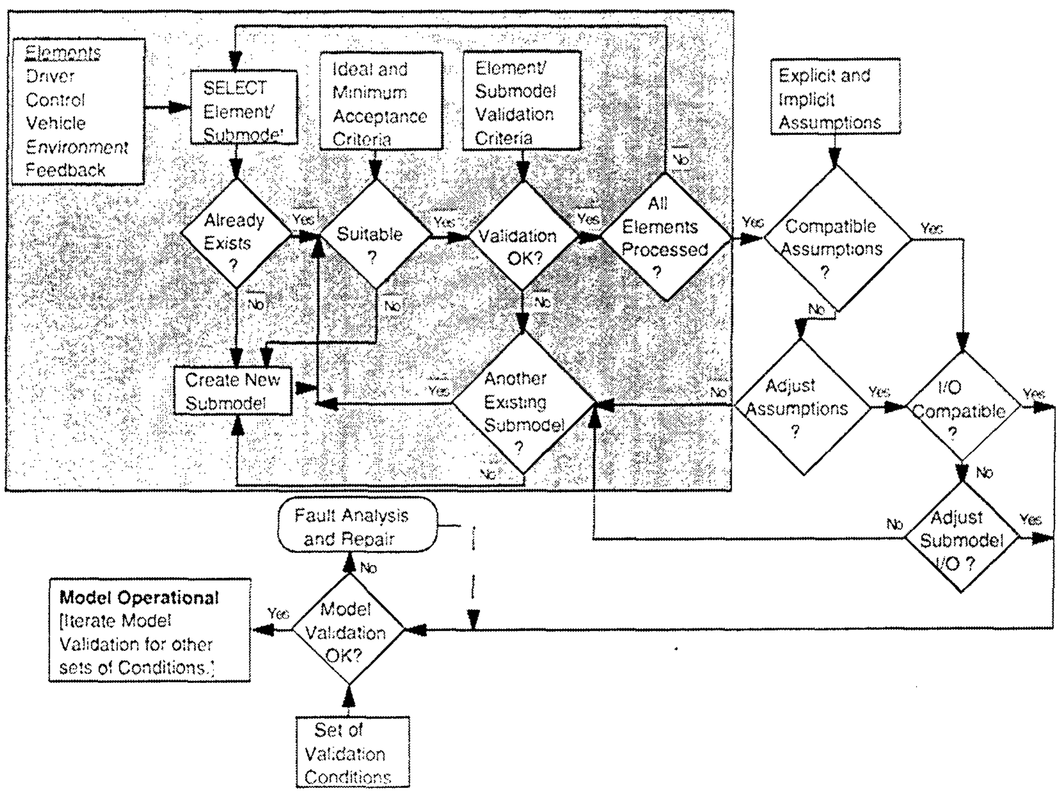


Figure 4. Implementation Strategy.

[33]Sometimes defined as "derivative models" that summarize the output of computational models or observations of a system's behavior (Lee, 1998).

The following comments are designed to help the reader understand Figure 4 better. The elements are those of the conceptual model except that the "sensors and displays" element is replaced by the more general term "feedback" to include sensing the vehicle's environment directly "through the windshield." The selection of a sub-model instead of an element allows for the situation in which a sub-model already exists for more than one element. Since "sub-model" is the more general term, it is used exclusively in the remaining discussion. A number of input entries shown in Figure 4 need to be determined: (a) the ideal and minimum set of acceptance criteria for an individual sub-model, (b) the validation criteria for this sub-model, (c) the explicit and implicit assumptions for each sub-model, and (d) a set of conditions to validate the comprehensive model. The term "adjust assumptions" allows for the possibility that a given sub-model may have parallel pathways with different assumptions, one set of which might be compatible with the assumptions of the other sub-models. The term "adjust submodel I/O" allows for the possibility that the input (output) coding might be readily changed to make it compatible with the output (input) of the other sub-models. If the model validation is not satisfactory, then a fault analysis and repair of the comprehensive model should be undertaken. The dashed line from this box indicates that the return may not go directly to "model validation." The return could be to any of the decision points within Figure 4. The exact point of return is determined by the findings of the fault analysis.

5. Future Work

Figure 4 shows that a large number of sub-models and other input are necessary to develop a predictive, comprehensive driver performance model. Many of these sub-models and other input are not known or have not yet been developed. Thus, the creation of a predictive, comprehensive driver performance model is a long-range goal. In the near term, we plan to model the characteristics of a simple vehicle and vary aspects of visual input to the driver to determine the effects of this variation on driver performance for both the direct and indirect modes of driving.

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13. ABSTRACT *(Maximum 200 words)*

A comprehensive model that combines the necessary aspects of vehicle characteristics, manual control theory, and human sensory and cognitive capabilities (and limitations) is needed to efficiently and effectively guide experiments and to predict or assess overall driver performance. Such a model would enable an Army program manager to rank competing workload configurations and scenarios in proposed vehicles and to select the one(s) most promising, thereby saving resources otherwise spent on the current process, that is, multiple hardware iterations of "design-test-fix."

At the present time, no such comprehensive model exists. This report discusses a conceptual framework designed to encompass the relationships, conditions, and constraints related to direct, indirect, and remote modes of driving and thus provides a guide or "road map" for the construction and creation of a comprehensive driver performance model.

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ERRATA

"Driver Performance Model: 1. Conceptual Framework"
ARL-TR-2581, December 2001

19 Dec 2001

Dear recipient of ARL-TR-2581:
As this report was in the process of being distributed, I became aware of the Joint Robotics Program (JRP) Master Plan for FY2001. Appendix B of this document establishes definitions of frequently used terms within the Robotics community. In interest of moving toward a common terminology among the various communities who deal with the operations of ground vehicles, I am taking this opportunity to point out discrepancies between some terms used in my report and those defined by JRP.

First, the conceptual framework discussed in ARL-TR-2581 assumes there is a human driver at all times, and that this driver receives continuous feedback from the vehicle's local environment either directly ("through-the-windshield"), or through sensors and displays. The JRP has defined "remote" to mean line-of-sight control, without the benefit of video feedback. Thus, the use of the term "remote" as used in ARL-TR-2581 is not appropriate. To bring the intended concept of ARL-TR-2581 into conformity with the JRP definitions, the word "remote" in ARL-TR-2581 should be replaced by: "teleoperated," and the phrase: "remote driver" should be replaced by word: "teleoperator." These replacements occur:

- in the heading of column 4 of Table 1,
- in Figure 1 (lower left side) and its caption (see also page v),
- in footnotes 14, 19, 21, 23, 31, and 32, and
- in the text on:
  - page 1 (4 places);
  - p.3 (2x),
  - p.4 (1x),
  - p.5 (1x),
  - p.6 (4x),
  - p.8 (1x),
  - p.11(3x), and

in the abstract on page ii (1x) and in Block 13 on page 21 (1x).
Delete the entry "remote driving" in Block 14 on page 21.

Once these replacements have been made, the last sentence of the first paragraph beginning with: "The teleoperation of..." no long makes sense, and should be replaced by: "Continuous control of an unmanned ground vehicle provides an example of teleoperated driving."

Next, the sentence that begins "Thus, autonomous ..." at the bottom of page 7 should be replaced by: "Thus, autonomous vehicles, and semi-autonomous vehicles which only occasionally require monitoring by a human, are still some time in the future. "

Finally, since JRP provides distinct definitions for the terms: autonomous, semi-autonomous, remote and teleoperated, footnote 23 is not true and should be deleted.

Once these changes are made, the terms used in ARL-TR-2581 will conform to the JRP definitions.

Please accept my apologies for this inconvenience.

Joseph M Heimerl

Joseph M. Heimerl

encl.: Appendix B of JRP Master Plan FY2001

Appendix B

TERMINOLOGY FOR THE JRP

FOREWORD

The purpose of this glossary is to establish baseline definitions for terms frequently used by the Joint Robotics Program (JRP) community. We have recognized for some time that, especially with an unprecedented technology, new terms are introduced that may cause confusion unless their meaning is somehow codified and their definitions are common across the community. The definitions contained herein will pertain as we move forward in achieving our vision for military ground robotic systems. We endeavored to make the definitions as succinct as possible.

Clearly, there are other glossaries and dictionaries that define terms used by the JRP. Examples are the JCS Pub 1-02 and IEEE documentation. Wherever possible, we defer to, and use the definitions from those sources. However, in some cases those definitions do not lend clarity to the military nature of Unmanned Ground Vehicles or to the nature of robotic systems. In those cases, we have taken license to depart from their definitions as required by the unique aspects of military ground robotics.

This will be a dynamic document. We are starting with a few terms, will publish them as an appendix to the JRP Master Plan, and continue at a steady pace as definitions increase. Ultimately, the glossary will reside as a document in the Joint Architecture for Unmanned Ground Systems. If the reader has comments/recommendations on this glossary, please send them to me.

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Appendix B
TERMINOLOGY FOR THE JRP

Artificial Intelligence. The programming and ability of a robot to perform functions that are normally associated with human intelligence, such as reasoning, planning, problem solving, pattern recognition, perception, cognition, understanding, learning, speech recognition, and creative response.

Automation. The capability of a machine or its components to perform tasks previously done by humans. Usually accomplished by a subsystem of a larger system or process, performance of tasks can be cued by humans or a point in the process. Examples are an autoloader in an artillery system or the welding of parts on an assembly line by machines.

Autonomous. A mode of control of a UGV wherein the UGV is self-sufficient. The UGV is given its global mission by the human, having been programmed to learn from and respond to its environment, and operates without further human intervention.

Classes of UGVs. The JRP postulates several classes of UGVs, based on weight:

- Micro: < 8 pounds
- Miniature: 8-30 pounds
- Small (light): 31-400 pounds
- Small (medium): 401-2,500 pounds
- Small (heavy): 2,501-20,000 pounds
- Medium: 20,001-30,000 pounds
- Large: >30,000 pounds

Cooperative operations. The ability of two or more UGVs to share data, coordinate their maneuver, and perform tasks synergistically.

Data link. The means of connecting one part of the UGV system with another part of the system for the purpose of transmitting and receiving data. Examples of technologies used as UGV data links are radio frequency, fiber optics, and laser.

Expendable. A UGV that may be consumed in use and may be dropped from stock record accounts when it is issued or used.

JAUGS. (Joint Architecture for Unmanned Ground Systems) An upper level design for the interfaces within the domain of Unmanned Ground Vehicles. It is a component-based, message-passing architecture that specifies data formats and methods of communication among computing nodes. It defines messages and component behaviors that are independent of technology, computer hardware, and vehicle platforms and isolated from mission. JAUGS is prescribed for use by the JRP in the research, development, and acquisition of UGVs.

Line-of-sight. (1) Visually, a condition that exists when there is no obstruction between the viewer and the object being viewed. (2) In radio frequency communications, a condition that exists when transmission and reception is not impeded by an intervening object, such as dense vegetation, terrain, man-made structures or the curvature of the earth, between the transmit and receive antennas.

Process

Man-machine interface. The means by which the human operator interacts with the UGV system. It includes the software applications, graphics, and hardware that allow the operator to effectively give instructions to or receive data from the UGV.

rapidly comprehend or understand

Manipulator. In robotics, a mechanism consisting of an arm and an end-effector. It contains a series of segments, jointed or sliding relative to one another, for the purpose of modifying, grasping, emplacing, and moving objects. A manipulator usually has several degrees of freedom.

Man portable. A UGV or components of a disassembled UGV, capable of being carried by one man over long distance without serious degradation of performance of his normal duties. The upper weight limit is 31 pounds.

Man transportable. A UGV usually transported in another vehicle that has integral provisions for periodic handling by one or more individuals for limited distances (100-500 meters). The upper weight limit is 65 pounds per individual.

Marsupial. A design concept for UGVs where a larger UGV carries one or more smaller UGVs, either inside it or attached to it for later deployment.

Mission module. A self-contained assembly installed on a UGV that enables the unmanned platform to perform functions that have military value. It can be easily installed and replaced by another type of mission module.

Mission planning. The process by which a human operator devises tactical goals, a route (general or specific), and timing for one or more UGVs. Considerations include terrain, threat, weather, location of friendly forces, fire support, and mission modules. The mission planning process may be accomplished on a computer or OCU for downloading to the UGV.

Mobility. The capability of a UGV to move from place to place, while under any method of control, in order to accomplish its mission or function.

Mode of control (also control mode). The manner by which a UGV receives instructions that govern its actions. Examples are remote control, semi-autonomous, etc.

Modularity. The property of flexibility built into a system by designing discrete units (hardware and software) that can easily be joined to or interface with other parts or units.

Navigation. The process whereby a UGV makes its way along a route that it planned, that was planned for it or, in the case of teleoperation, that a human operator sends it in real time.

Negative obstacle. A terrain feature that presents a negative deflection relative to the horizontal plane of the UGV such that it prevents the UGV's continuation on an original path. Examples are depressions, canyons, creek beds, ditches, bomb craters, etc.

Non-line-of-sight. (1) Visually, a condition that exists when there is an obstruction between the viewer and the object being viewed. (2) In radio frequency communications, a condition that exists when there is an intervening object, such as dense vegetation, terrain, man-made structures, or the curvature of the earth, between the transmit and receive antennas, and transmission and reception would be impeded. Non-line-of-sight communications implies communication across this normally non-line-of-sight distance/terrain. An intermediate ground, air, or space based retransmission capability may be used to remedy this condition.

Obstacle avoidance. The action of a UGV when it takes a path around a natural or man-made obstruction that prevents continuation on its original path.

Obstacle detection. The capability of a UGV or its operator to determine that there is an obstruction, natural or man-made, positive or negative, in its path.

Obstacle negotiation. The capability of a UGV or its operator to navigate through or over an obstacle once it's detected and characterized as negotiable.

Operator Control Unit. (OCU) The computer(s), accessories, and data link equipment that an operator uses to control, communicate with, receive data and information from, and plan missions for one or more UGVs.

Payload. The load (expressed in pounds of equipment, gallons of liquid, or other cargo) which the UGV is designed to transport under specified conditions, in addition to its unladen weight.

Plug-and-play. The ability to quickly remove one type of mission module from a UGV and replace it with another type, the new mission module being ready for immediate use.

Remote control. A mode of control of a UGV wherein the human operator, without benefit of video feedback, directly controls on a continuous basis the actions of the UGV using visual line-of-sight cues.

Retro-traverse. A behavior of a UGV in which, having recorded navigation data on where it has been, it autonomously retraces its route to a point where it can continue its mission.

Robot. A machine or device that works automatically or operates by remote control.

Robotics. The study and techniques involved in designing, building, and using robots.

Semi-autonomous. A mode of control of a UGV wherein the human operator plans a mission for the UGV, it conducts the assigned mission, and requires human operator intervention when the UGV infrequently needs further instructions.

Telepresence. The capability of a UGV to provide the human operator with some amount of sensory feedback similar to that which the operator would receive if he were in the vehicle.

Teleoperation. A mode of control of a UGV wherein the human operator, using video feedback and/or other cues, directly controls on a continuous basis the actions of the UGV.

Tether. A fiber optic or other communications cable that connects the OCU to the UGV platform.

Unmanned Ground Vehicle (UGV). A powered, mobile, ground conveyance that does not have a human aboard; can be operated in one or more modes of control (autonomous, semi-autonomous, teleoperation, remote control); can be expendable or recoverable; and can have lethal or non-lethal mission modules.

Unmanned Systems. A grouping of military systems, the common characteristic being there is no human operator aboard. May be mobile or stationary. Includes categories of unmanned ground vehicles (UGV), unmanned aerial vehicles (UAV), unmanned underwater vehicles (UUV), unattended munitions (UM) and unattended ground sensors (UGS). Missiles, rockets, and their submunitions, and artillery are not considered unmanned systems.

Waypoints. Intermediate locations through which a UGV must pass en route to a particular destination.

Waypoint navigation. The process whereby a UGV makes its way along a route of planned waypoints that it planned or were planned for it.

Zamboni pattern. The path traveled by a UGV that is elliptical in nature, such that an entire prescribed area is covered by the UGV's mission modules or ground track. Named after an ice re-surfacing machine of the same name used at hockey games.